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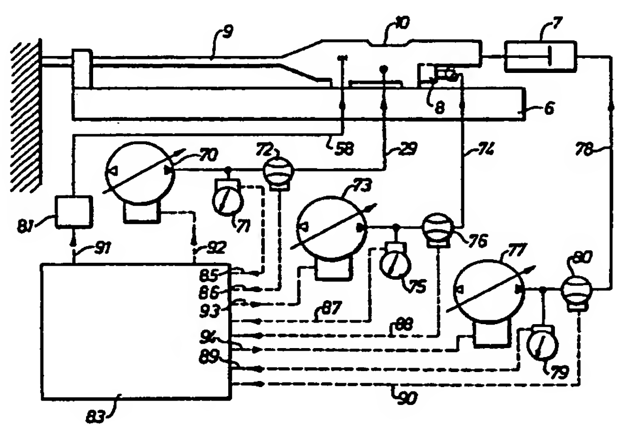
(71) Applicant: Atlas Copco Aktiebolag, Nacka (SE)

(72) Inventor: Strömdahl, Carl Akesson, 5, Wenströmsvägen, S-115 43 Stockholm (SE)

(74) Representative: Aslund, Roland et al, c/o Atlas Copco Management Consulting AB Patent Department, S-105 23 Stockholm (SE)

(54) **A rock drilling apparatus and a method of optimizing percussion rock drilling.**

(57) The impact velocity and impact frequency of the hammer piston of a percussion rock drill are varied in incremental steps in order to find the maximum penetration rate. The frequency and impact velocity are so varied that the impact power is kept substantially constant all the time. A micro-computer is used to control the process.



EP 0 112 810 A2

A rock drilling apparatus and a method of optimizing percussion rock drilling

This invention relates to a rock drilling apparatus comprising a percussive rock drill in which a hammer piston of a rock drill is arranged to be powered to repeatedly impact upon an anvil coupled to a drill string, and means for controlling the impact velocity and impact frequency of the hammer piston. The invention also relates to a method of optimizing percussion rock drilling.

Such a rock drill is described for example in EP-A-0035005 Although he has the possibility to select the impact velocity it is for many reasons difficult or impossible also for a skilled operator to select the correct impact velocity. One of the reasons is that a higher energy output almost always results in a higher penetration rate even if the drilling becomes more inefficient. When the drilling is inefficient the life of the drill stem and drill bit will be reduced by the shock wave energy that is reflected against the rock instead of used for demolition. For efficient drilling, the impact velocity of a hammer should vary with the rock properties and it should also vary with the sharpness of the drill bit. When the drill bit is sharp, the impact velocity should be reduced and then it should be gradually increased also when the rock properties do not change.

It is an object of the invention to make it possible to drill at or at least close to the maximum drilling efficiency.

The invention will be described with reference to the accompanying drawings.

Fig 1 is a diagram of the system for powering and controlling a percussion rock drill.

Fig 2 is a fragmentary and schematic longitudinal section through a rock drill which can be used together with the system of Fig 1.

Fig 3 is a transverse section along line 3-3 in Figs 2 and 4.

Fig 4 is a section on line 4-4 in Fig 2.

Fig 5 is a section on line 5-5 in Fig 2.

In Fig 1, a hydraulic percussion rock drill 10 is shown which is mounted on a feed beam 6 to be slidable therealong by means of a bidirectional, positive displacement, hydraulic feed motor (schematically indicated at 7) coupled to a non-illustrated chain or the like feeding arrangement. The rock drill 10 has a hydraulic rotation motor 8 which rotates a drill stem 9 and it has a hammer piston 13 (shown in Fig 2) which impacts on an anvil element 14 (Fig 2) which is coupled to the drill stem 9.

The rock drill will be more closely described with reference to Fig 2. It comprises a housing 11 forming a cylinder 12 in which the hammer piston 13 is reciprocable to impact upon the anvil element 14 in the form of an adapter to which the drill stem 9 is coupled. A shoulder 15 on the anvil element takes support on a sleeve 16 that abuts on a damping piston 17 for damping the reflected compressive shock waves. The damping piston 17 is forced forwardly into its foremost position as shown by the hydraulic pressure in a cylinder chamber 18 that is constantly pressurized through a passage 19. The rotation motor 8 (indicated on Fig 1 only) rotates the adapter 14 via a shaft 61 with a gear 62 that meshes with a rotatably journalled chuck 64. The chuck 64 has a chuck bushing 65 that is in engagement with a widened portion 63 of the adapter 14. The adapter 14 is limitedly slidable relative to the chuck 64 but it is forced to co-rotate with the chuck 64 because of the non-circular form of the inter-engaging surfaces as can be seen in Fig 5. The damping piston 17 will temporarily yield when a reflected shock wave from the drill stem 9 reaches it, and it will again force the adapter 14 forwardly into the illustrated position before the next impact. Without a damping piston 17, high stresses will be imparted on the housing 11.

The hammer piston 13 has two lands 20, 21 so that a front cylinder chamber 22, a rear cylinder chamber 23 and an intermediate cylinder chamber 24 are formed between the hammer piston 13 and the cylinder 12. The hammer piston 13 is driven forwardly by the pressure acting on its annular surface 25 and driven rearwardly by the pressure acting on its annular surface 26. A valve 27 is connected to an inlet 28 coupled to a source of high pressure hydraulic fluid and to an outlet 29 coupled to tank. Accumulators 30, 31 are coupled to the inlet 28 and the outlet 29 respectively. The intermediate cylinder chamber 24 is constantly connected to the outlet 29 by means of a passage 29a. The valve 27 is coupled to the rear cylinder chamber 23 by means of a supply passage 32 and to the front cylinder chamber 22 by means of a supply passage 33. The valve 27 has a valving spool 34 which in its illustrated position connects the rear cylinder chamber 23 to pressure and the front cylinder chamber 22 to tank. The spool 34 has cylindrical end portions 35, 36, the end faces of which form control piston surfaces that are subject to the pressure in control passages 37, 42 that each are branched into ten branches so that they each have ten ports respectively into the cylinder 12. On Fig 2, only four branches 38-41 and 43-46 of the control passages 37 and 42, respectively, are shown. In Fig 4, however, all ten branches of the control passage 42 are shown. A cylindrical pin 48 with two cylindrical recesses 49, 50 is slidable with a tight fit in a bore 47.The recesses 49, 50 form parts of the control passages 37, 42, respectively. Intergral with the pin 48, there is a control piston 55 on which the pressure in a cylinder chamber 56 acts to balance the force of a spring 57. A control passage 58 leads to the cylinder chamber 56. From Fig 4, it can be seen that the ports of the ten branches of the control passage 37 into the cylinder 12 axially overlap one another but are discrete as are the ports of the ten branches of the control passage 42.

The housing 11 with the cylinder 10, the hammer piston 13, the valve 27, the pin 48, the accumulators 30, 31 and the various passages form the impact motor of the rock drill.

The operation of the impact motor of Fig 2 will now be described. The hammer piston 13 is shown in Fig 1 moving forwardly in its work stroke (to the left in Fig 1), and the valve spool 34 is then in its illustrated position. When the branch 45 of the control passage 42 is opened to the rear cylinder chamber 23, the control passage 42 will convey pressure to the control piston 36 so that the valve spool 34 is moved to the right in Fig 1. The valve spool 34 should preferably finish its movement at the very moment the hammer piston 13 impacts upon the anvil 14. Thus, the pressure existing in the front cylinder chamber 22 from the moment of impact moves the hammer piston 13 rearwardly until the branch 40 of the control passage 37 is opened to the front pressure chamber 22. Then, the control passage 37 conveys pressure to the control piston surface 35 which moves the valve spool 34 back to its illustrated position so that the rear cylinder chamber 23 is again pressurized. The pressure in the rear cylinder chamber 23 retards the hammer piston 13 and accelerates it forwardly again so that the hammer piston 13 performs another work stroke.

The valve spool 34 has annular surfaces 52, 53 and internal passages 51, 54 which hold the valve spool in position during the periods when the control pistons 35, 36 do not positively hold the valve spool 34. The annular surfaces 52, 53 are smaller than the end faces of the pistons 35, 36.

When the pin 48 is in its illustrated position, the port of the branch 40 of the control passage 37 and the port of the branch 45 of the control passage 42 are the ports that make the valve spool shift position. The outer ports are inactivated. In other positions of the pin 48 one pair of the three pairs of ports 38, 43; 39, 44 and 41, 46, respectively, is selected to cooperate to control the valve.

The first one of the unblocked branches 38-41 that is opened to the front cylinder chamber 22 during the return stroke of the hammer piston initiates the valve spool 34 to shift position. Thus, the axial position of the pin defines the stroke length of the hammer piston. The axial distances between the ports into the cylinder 12

of the branches 43-46 are smaller than the corresponding distances between the ports into the cylinder of the branches 38-41. For convenience, the branches and their ports into the cylinder 12 are referred to as having the same reference numeral. The axial positions of the ports 43-46 in the cylinder 12 are such that for each stroke length the selected one of the ports 43-46 is uncovered a distance before the impact position of the hammer piston, and the distance is such that the valve spool has just moved to its position for pressurizing the front pressure chamber when the hammer piston 13 impacts on the anvil 14. The distances between the ports 43-46 are such that the selected port is uncovered the same period of time before impact occurs independently of which one of the ports that has been selected.

The system for operating the rock drill 10 shown in Fig 2 will now be described with reference to Fig 1.

The feed line 29 of the impact motor of the rock drill 10 shown in Fig 2 is coupled to an adjustable hydraulic pump 70 and there is a pressure gauge 71 and a flow meter 72 in the line 29. The return line 28 from the impact motor is not shown in Fig 2 and other return lines are not shown either in order to make the figure more clear. The hydraulic motor 8 is coupled to an adjustable hydraulic pump 73 through a line 74 that includes a pressure gauge 75 and flow meter 76. The feed motor 7 is coupled to an adjustable hydraulic pump 77 through a line 78 that includes a pressure gauge 79 and a flow meter 80.

The control line 58 for controlling the pin 48, that is, for controlling the stroke length at the hammer piston 13 is coupled to an electric-hydraulic converter 81 that is fed with hydraulic oil through a non-illustrated line. The control valves and direction control valves in the supply lines 29, 74, 78 are not illustrated.

A micro computer including the necessary input/output interfaces has been designated by 83. Reference numerals 85-90 refer to electric input lines of the micro computer and reference numerals 91-94 refer

to electric output lines of the micro computer. Electrical wiring is generally illustrated by dashed lines.

The penetration rate of the drill stem 9 is sensed by the flow meter 80 as the oil flow to the feed motor 7 and the micro computer 83 is programmed to control the stroke length of the hammer piston 13 by controlling the position of the control pin 48 through the converter 81.

The information of the power output of the pump 70, i.e. the power input of the impact motor, is sensed by the pressure gauge 71 and flow meter 72 as the pressure and flow of the hydraulic oil in line 29, and the computer 83 controls the displacement of the pump 70 via the line 92 either directly or, if the pump 70 is pressure compensated, by defining the pressure. The hydraulic efficiency factor of the impact motor varies with the position of the control pin 48 and the pressure and flow in the input line 29 to the impact motor. This hydraulic efficiency factor has been measured for the impact motor in question and its variation has been incorporated in the program of the computer. Thus, the product of the pressure, the flow, and the hydraulic efficiency factor represents the impact power delivered by the hammer piston 13 to the drill stem 9.

The computer is programmed to start drilling with a pre-determined position of the control pin 48 and a pre-determined pressure in the supply line 58 to the impact motor. The computer reads the penetration rate and then it applies a small change of the position of the pin 48 in a pre-determined direction so that another pair of branches 38, 43; 39, 44; and 41, 46 of the control passages 37, 42 will be effective. The computer controls the pump 70 so that the impact energy output of the hammer piston 13 will be maintained constant. This means that the pump pressure and the impact rate increase as the stroke length is decreased and vice versa. The computer again reads the penetration rate. If the penetration rate has increased, the computer repeats the change as long as the penetration rate increases. If or when the penetration rate decreases, the computer applies a pre-determined change in the

position of the pin 48 in the other direction and repeats the change as long as the penetration rate increases. Then, when the penetration rate again decreases, the computer again applies a change in the first direction. The penetration rate can for example be controlled under a period of a few seconds, and an entire cycle may take less than 10 seconds.

In the sequence described above the penetration rate is maximized. The maximum penetration rate represents the maximum drilling efficiency for the constant impact power selected.

Alternatively to seeking the maximum drilling efficiency for a constant impact power, one can seek the maximum drilling efficiency for an impact power that varies somewhat. It might for example be desirable to utilize the maximum output power of a constant power pump or to utilize the maximum power of an electric motor driving the pump. The pump could then be a variable displacement pump that is not coupled for constant power.

In these cases, the quotient of the penetration rate and the impact power should be maximized. The drilling efficiency is defined as this quotient when the hole diameter is constant. Thus, when the impact power is not held constant, the maximum penetration rate does not represent the maximum drilling efficiency.

If the impact power is held constant, that is, when the pump output varies to compensate for the variation of the hydraulic efficiency factor of the impact motor, the method of finding the maximum drilling efficiency can be carried out manually since the pump output can be controlled without a computer, e.g. its displacement can be mechanically varied by a cam curve in response to the pump pressure if the pump motor runs at a constant speed. In such a manually controlled system, the pressure in the control line 58 in Fig 2 can be manually controlled through a pressure regulator so that the position of the pin 48 can be remotely controlled from the operator's panel. A penetration rate display can be used that is coupled to a flow meter that corresponds to the flow meter 80 in Fig

1. A cycle for finding the maximum penetration rate will then not be carried out in a few seconds, but it can be carried out for example during the drilling of the first blast hole drilled in a tunnel face. Then a few blast holes can be drilled with the control pin 48 fixed in the position which has been found to represent the maximum penetration rate before another cycle for finding the maximum penetration rate is again carried out.

The drill bit should be indexed a pre-determined angle between the impacts, and the angle is specific to certain type of drill bit. Thus, the rotation can simply be pre-determined to vary linearly with the impact rate. The computer can be programmed for various drill bits so that the operator need only define the type of drill bit.

The feed force need not be varied, but it can be varied. The feed force that is necessary varies invertedly to the variation of the impact velocity of the hammer piston 13 when the impact energy output is kept constant. The programming for such a control of the feed force is also very simple.

The hydraulic efficency factor as described above can be measured for the specific rock drill, but it can also be measured for a few rock drills of a series of rock drills. The efficiency factor may be somewhat different for different rock drills, but the variation of the factor will be similar. Therefore, mean values of the factor can be used for all the rock drills and still the impact energy output will be substantially constant for each rock drill although it might vary somewhat between the rock drills.

It is of course not necessary that the impact velocity and impact frequency of the hammer piston be controlled by a hydraulically operated control pin 48 as described. The remote control of the pin can for example be purely electrical. It is not necessary that the pin controls the control passage 42. The control passage 42 may instead have only one port into the cylinder 12. The invention as defined in claim 1 can also be applied to almost any kind of

hydraulic impact motors and not only to the impact motor illustrated in Fig 2, for example to the hydraulic impact motors described in DE-A 2658455.

The feed beam 7 illustrated in Fig 1 may be mounted on a boom of a mobile drilling rig, for example a mobile drilling rig for drilling the blast holes in tunnel driving. Then, the computer 83 and the pumps 70, 73, 77 as well as the flow meters 72, 76, 80 and the pressure gauges 75, 79 can be mounted on the chassis of the drilling rig. The pressure gauge 71 could be mounted on the chassis but it should preferably be connected close to the rock drill so that it is downstream of possible pressure drops in the conduit 58. EP-A-0004838 can be mentioned as illustrating a typical boom of a rock drilling rig for drilling the blast holes in tunnel driving. The feed beam 7 can be mounted on such a boom.

Claims:

1. A rock drilling apparatus comprising: A percussive rock drill in which a hammer piston (13) is arranged to be powered to repeatedly impact upon an anvil (14) coupled to a drill string (9), and means (83) for controlling the impact velocity and impact frequency of the hammer piston,
c h a r a c t e r i z e d i n
that means (80) are arranged for reading the penetration rate of the drill string and said means (83) for controlling the impact velocity and impact frequency of the hammer piston (13) is arranged to repeatedly apply changes in the impact velocity and in the impact frequency in order to seek the maximum penetration rate while keeping the impact power substantially constant.

2. A rock drilling apparatus according to claim 1,
c h a r a c t e r i z e d i n
that the rock drill (11) is mounted on a feed beam (6) and slidable therealong, and a hydraulic feed motor (7) is coupled to move the rock drill along the feed beam, said means for reading the penetration rate of the drill string comprising a flow meter (80) in the power system for the feed motor.

3. A rock drilling apparatus according to claim 1 or 2,
c h a r a c t e r i z e d i n
that said means for controlling the impact velocity and impact frequency comprises a micro computer (83).

4. A rock drilling apparatus comprising: A percussive rock drill in which a hammer piston (13) is arranged to be powered to repeatedly impact upon an anvil (14) coupled to a drill string (9), and means (83) for controlling the impact velocity and impact frequency of the hammer piston,
c h a r a c t e r i z e d i n
that means (80) are arranged for reading the penetration rate of the drill string and said means (83) for controlling the impact velocity and impact frequency of the hammer piston (13) is arranged to

repeatedly apply changes in the impact velocity and in the impact frequency in order to seek the maximum of the quotient of the penetration rate and the impact power.

5. Method of optimizing percussion rock drilling by varying the impact velocity and impact frequency of the hammer piston (13) of a percussion rock drill (10) which impacts on a drill string (9), characterized in that the impact velocity and impact frequency of the hammer piston are varied in order to seek the maximum penetration rate while the impact power is held substantially constant.

6. Method according to claim 5, characterized in that the rotation speed of the drill string (9) is so varied that it is indexed a substantially constant angle between the impacts when the impact frequency is varied.

7. Method of optimizing percussion rock drilling by varying the impact velocity and impact frequency of the hammer piston (13) of a percussion rock drill (10) which impacts on a drill string (9), characterized in that the impact velocity and impact frequency of the hammer piston are varied in order to seek the maximum of the quotient of the penetration rate and the impact power.

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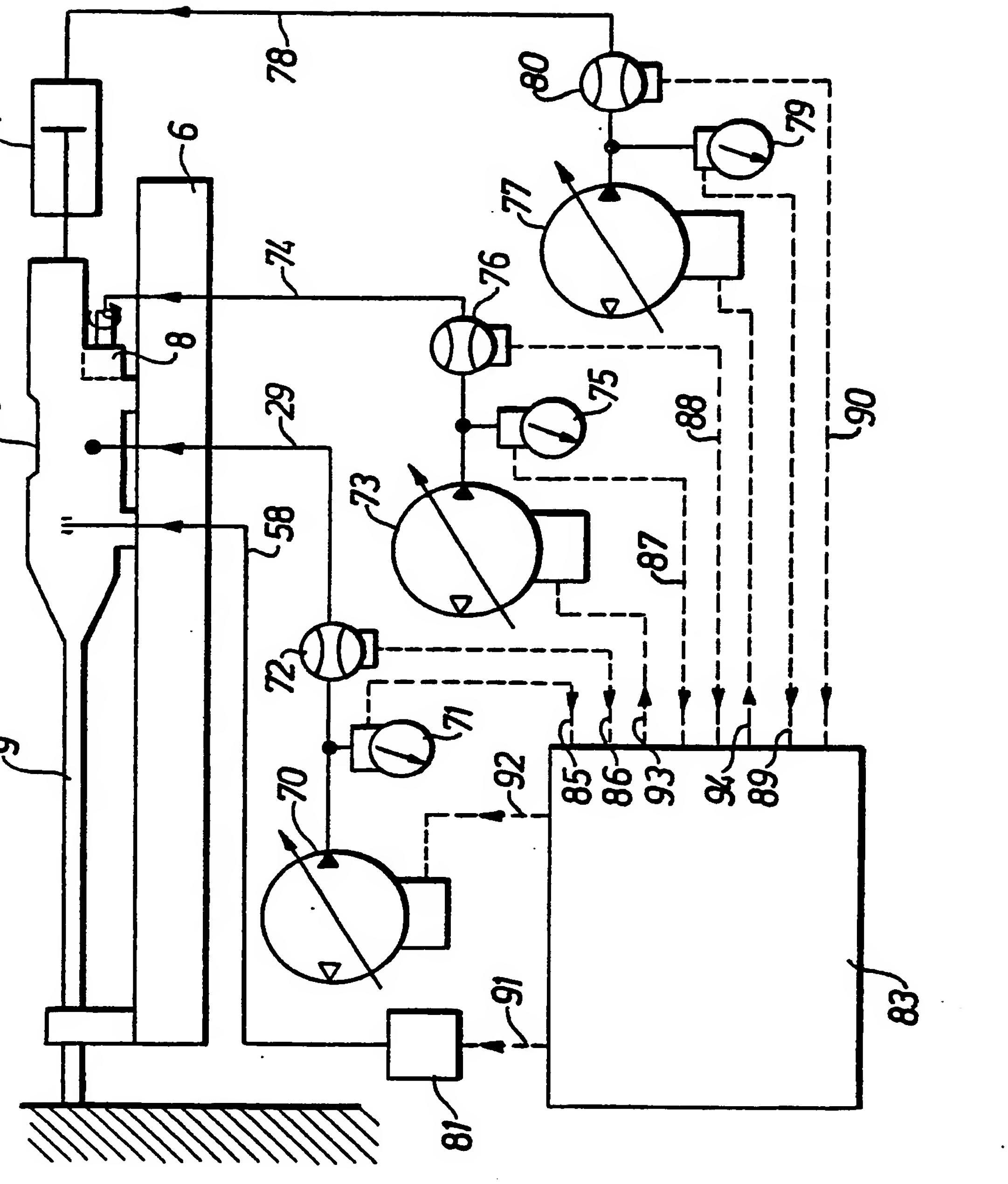

Fig.1

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Fig.2

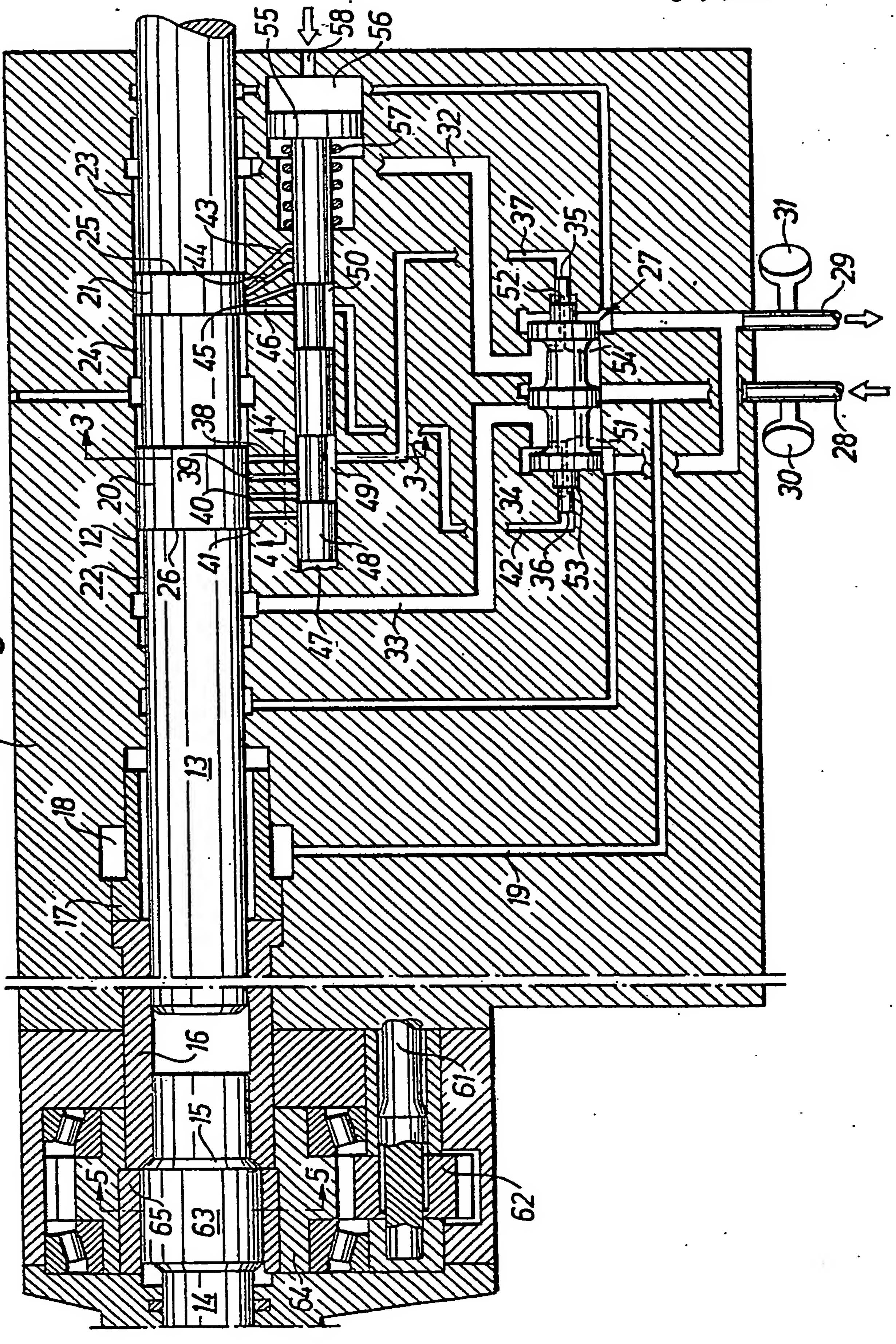

Fig.3

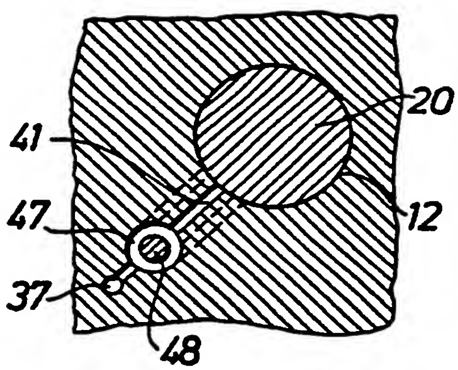

Fig.4

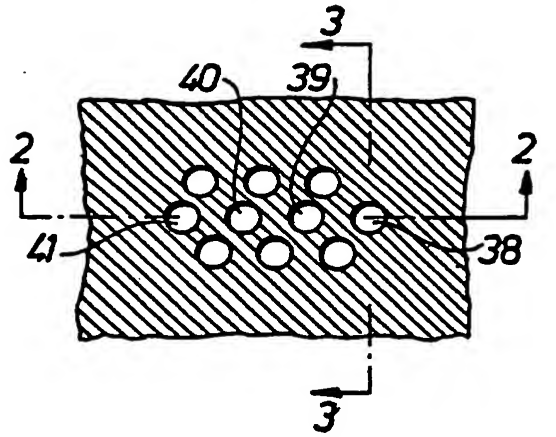

Fig.5